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Development of a Dynamic Biomechanical Model for Load Carriage: Phase II Part C&D

User's Manual V 3.0: Dynamic Load Carriage Compliance Tester Automated Test Cell

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Abstract

This report represents the User's Manual for the 3D dynamic load carriage simulator and automated test cell. Contained within this report are the hardware and software components in addition to instructions for users to run the system. If the system is ever moved to a new location, this manual must be taken with it for set-up and data acquisition. The changes to the automated programmable motion control system have created a number of functions not possible with the previous system. These functions include: 1) highly repeatable motion profiles independent of the operator; 2) determination of the system stiffness under dynamic conditions; 3) provision for quantitative validation of models of load carriage devices; 4) determination of the frequency response of LC suspension systems; and 5) creation of an automated test cell requiring minimal operator expertise and low cost for possible sale to support other countries modelling efforts.

Résumé

Le présent rapport est le manuel de l’utilisateur du simulateur de transport de charge dynamique tridimensionnel (3D) et de la cellule d’essai automatisée. Le rapport a pour objet les éléments matériels et logiciels du système ainsi que les instructions d’utilisation du système. Si le système est déménagé à un nouvel emplacement, le manuel doit l’accompagner afin de permettre la configuration du système et l’acquisition des données. Les changements apportés au système automatisé programmable de commande des mouvements ont donné accès à des fonctions qui n’existaient pas dans le système précédent, notamment : 1) profils de mouvements très reproductibles, indépendants de l’opérateur, 2) détermination de la rigidité du système dans des conditions dynamiques, 3) validation quantitative de modèles de systèmes de transport de charge, 4) détermination de la réponse en fréquence des systèmes de suspension de transport de charge et 5) création d’une cellule d’essai automatisée peu coûteuse nécessitant peu de compétences de la part de l’opérateur, qui pourrait être vendue afin de soutenir les activités de modélisation d’autres pays.

Executive Summary

The Compliance tester was originally developed to assess the stiffness of equipment worn on the torso using quasi-static motion. Movement of the test torso was achieved using a series of hand operated pulleys and cables. This required an operator to attempt to produce a constant rate of displacement that introduced some variability in the methodology and confined testing to quasi-static conditions. The purpose for the revised 3D Compliance tester design modification was to support the development of a biomechanical model of human load carriage. The device will initially furnish input values for the dynamic stiffness variables during initial modeling stages. At later stages of the model development, the apparatus can be used to validate the model by comparing the model predicted stiffness responses to a different range of motion profiles.

In Phase 1 Part A, 2D changes were made to the LC Compliance tester. This report represents the addition of the 3D function as well as the User's Manual in running the device. The changes to the automated programmable motion control system have created a number of functions not possible with the previous system. These functions include: 1) highly repeatable motion profiles independent of the operator; 2) determination of the system stiffness under dynamic conditions; 3) provision for quantitative validation of models of load carriage devices; 4) determination of the frequency response of LC suspension systems; and 5) creation of an automated test cell requiring minimal operator expertise and low cost for possible sale to support other countries modelling efforts

The 3D hardware and software components for the dynamic load carriage simulator and automated test cell in this report in addition to providing the user with instructions on running the system. If the system is ever moved to a new location, this manual must be taken with it for set-up and data acquisition.

Sommaire

À l’origine, l’appareil d’essai de conformité a été développé pour évaluer la rigidité de l’équipement porté sur le torse dans des conditions de mouvement quasi-statiques. Le torse d’essai était mû au moyen d’une série de poulies et de câbles manipulés par un opérateur. Ce dernier devait alors essayer de produire une vitesse de déplacement constante. Cela a eu pour effet de créer une certaine variation dans la méthode et de limiter les essais à des conditions quasi-statiques. Les modifications apportées à l’appareil d’essai de conformité de transport tactique 3D avaient pour but d’appuyer l’élaboration d’un modèle biomécanique de transport de charge par une personne. Durant les premières étapes de la modélisation, l’appareil fournira les valeurs d’entrée pour les variables de rigidité dynamique. Durant des étapes ultérieures, il pourra être utilisé pour valider le modèle en comparant les réponses de rigidité prévues avec différents profils d’amplitude de mouvement.

À la partie A de la phase 1, des modifications bidimensionnelles ont été apportées à l’appareil d’essai de conformité de transport tactique. Le présent rapport traite de l’ajout des fonctions tridimensionnelles et constitue le manuel d’utilisation du dispositif. Les changements apportés au système automatisé programmable de commande des mouvements ont donné accès à des fonctions qui n’existaient pas dans le système précédent, notamment : 1) profils de mouvements très reproductibles, indépendants de l’opérateur, 2) détermination de la rigidité du système dans des conditions dynamiques, 3) validation quantitative de modèles de systèmes de transport de charge, 4) détermination de la réponse en fréquence des systèmes de suspension de transport de charge et 5) création d’une cellule d’essai automatisée peu coûteuse nécessitant peu de compétences de la part de l’opérateur, qui peut être vendue afin de soutenir les activités de modélisation d’autres pays.

Le rapport décrit les éléments matériels et logiciels 3D du simulateur de transport de charge dynamique et de la cellule d’essai automatisée et contient les instructions d’utilisation du système. Si le système est déménagé à un nouvel emplacement, le manuel doit l’accompagner afin de permettre sa configuration et l’acquisition des données.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

This test using the Compliance tester is based on the assumption that normal human gait patterns tend to minimize peoples' energy cost by optimising the interplay between body translation, rotation, potential and kinetic energies.

Immobilisation of the torso has been shown to increase a person's energy expenditure in walking at moderate speeds by about 10%.[1] Energy cost was more than twice that of carrying a 5kg weight about the waist. When this concept is applied to the evaluation of load carriage systems, the biomechanical conclusion is: the greater the resistance to normal body movement, the greater the baseline energy cost for a load carriage system. Torsional compliance is also necessary to assure free relative motion between the shoulders and hips during agility activities. Rigidity of a Load Carriage System (LCS) is inversely correlated, (r^2>0.86)[2] to several performance parameters such as: comfort of the user and a wearer's ability to perform whole body motions or upper arm/shoulder mobility tasks (such as moving their arms to the front or overhead).

Although the design of load carriage systems varies widely, the human form must carry all of them. To that end, the test apparatus consists of a human torso shape with independent thorax and pelvic sections. These sections rotate and pivot relative to each other through the required ranges of motion. Cyclic motion is generated using a programmable motion control system (Compumotor®; Parker Hannifin Corporation). Data acquisition, motion control and the user interface were realized with LabVIEW™ v6.1 (National Instruments) allowing integration of these three functions. This integration greatly reduces the number of operator interventions required during testing. Motions for forward and medial/lateral flexion and upper torso counter-rotation are fully automated. Additional motion profiles may be created using Motion Architect Shell V3.5 software ©Parker Hannifin Corporation.

The resistance of a LC system to torsion, forward flexion, and medial/lateral flexion is measured in three separate tests using bending beam and torsion load cells, which are described in detail in section 2. The LC Compliance tester determines a load carriage system's inherent resistance to human motion.

2.0 Description of System Components

2.1 General Overview

The LC Compliance Tester consists of:

A. 50 percentile male mannequin body form
B. Steel Test Frame
C. Horizontal Linear Actuator
D. Load Transfer Assembly
E. Data Acquisition/Motion Control Computer
F. Movable base

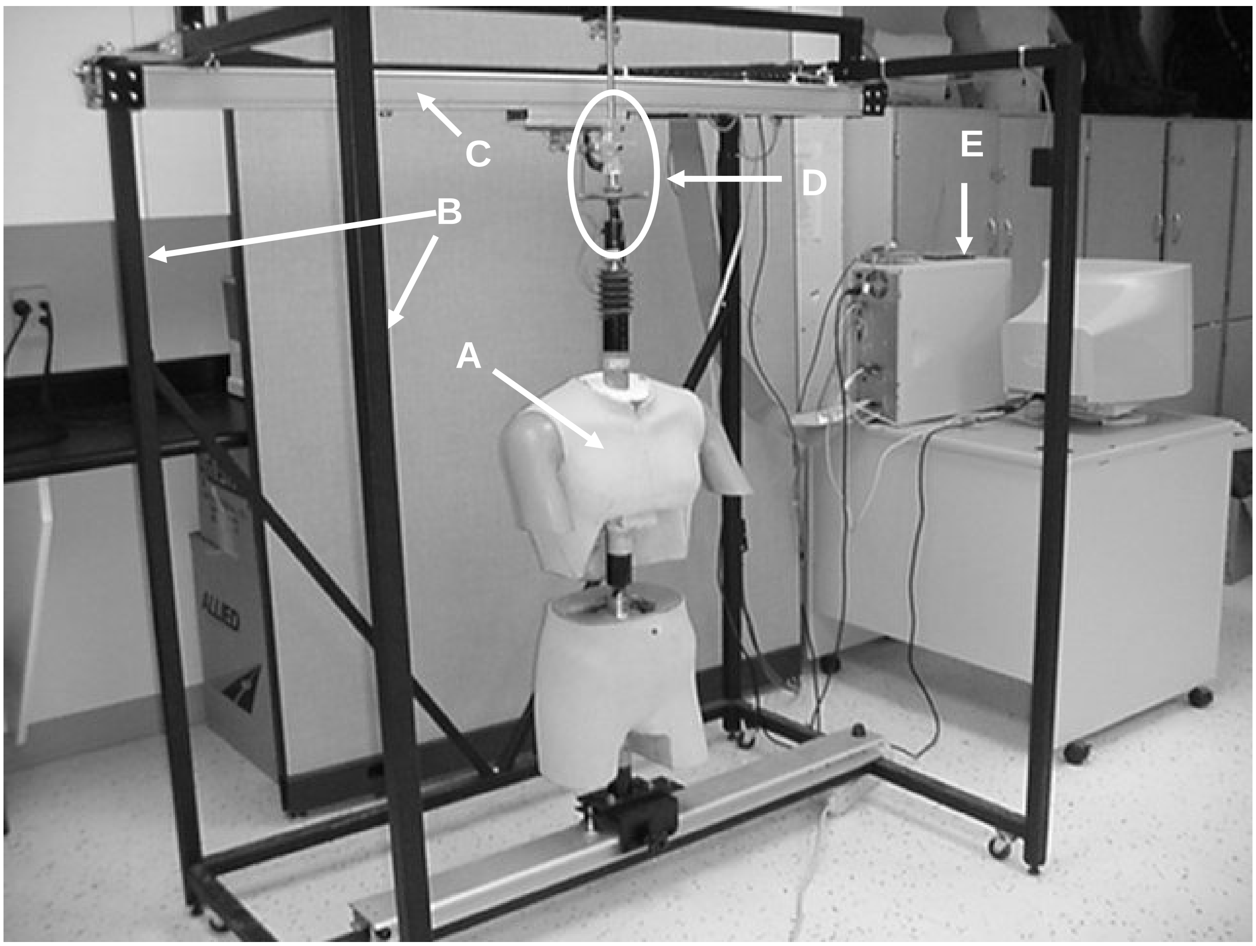
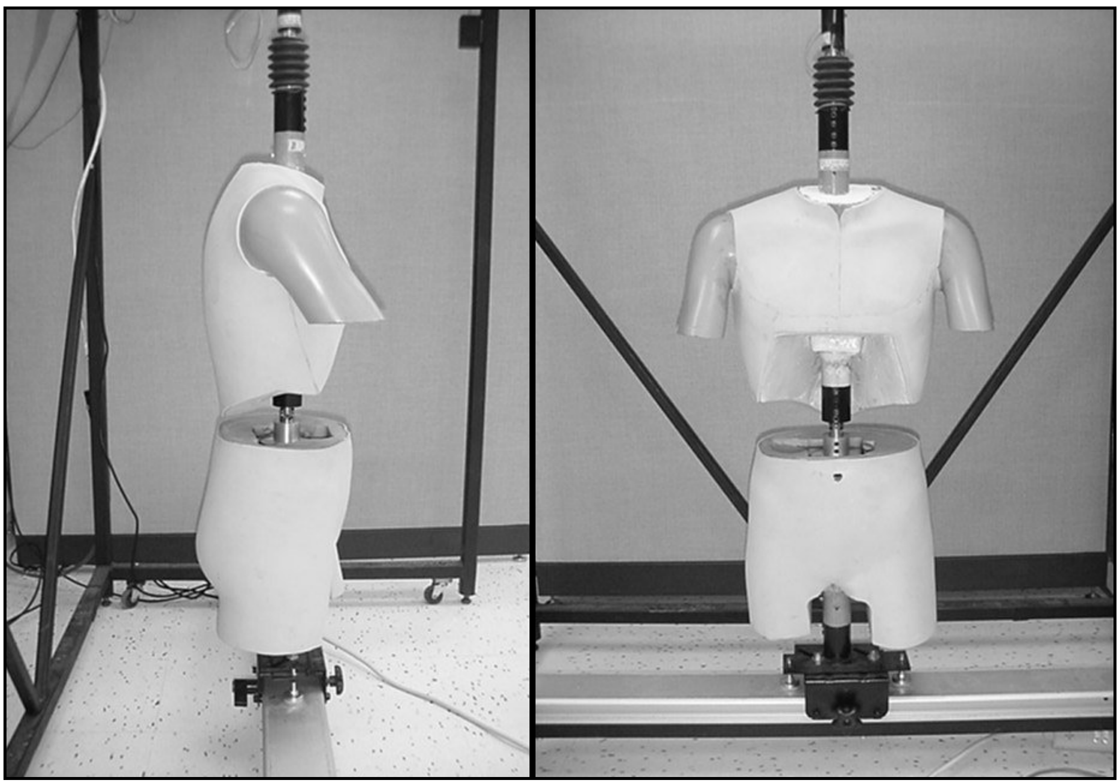


Figure 1. LC Compliance Test Cell

The test cell is configured for a lateral flexion test. Note the spur gear is in the lower position and the torso is facing perpendicular to the actuator travel in the central position.

2.2 Anatomical Torso

The 50 percentile articulated torso is shown in Figure 2. It is covered with a 5.0 mm layer of compliant material, Bocklite®. The upper torso of the model can bend forward, sideways or twist using a custom built ball and socket bearing located at the L3/L4 location of the human spine. Only one degree of freedom is active for each type of test. For all testing, the lower portion of the model is rigidly fixed to a steel support frame.



A. Side View B. Front View

Figure 2. 50 Percentile Anatomical Torso

The anatomical trunk model allows relative rotation of the upper torso with respect to the lower portion about each of the three axes. Cutouts on the upper torso are necessary to prevent binding during bending tests.

2.3 Load Transfer Assembly

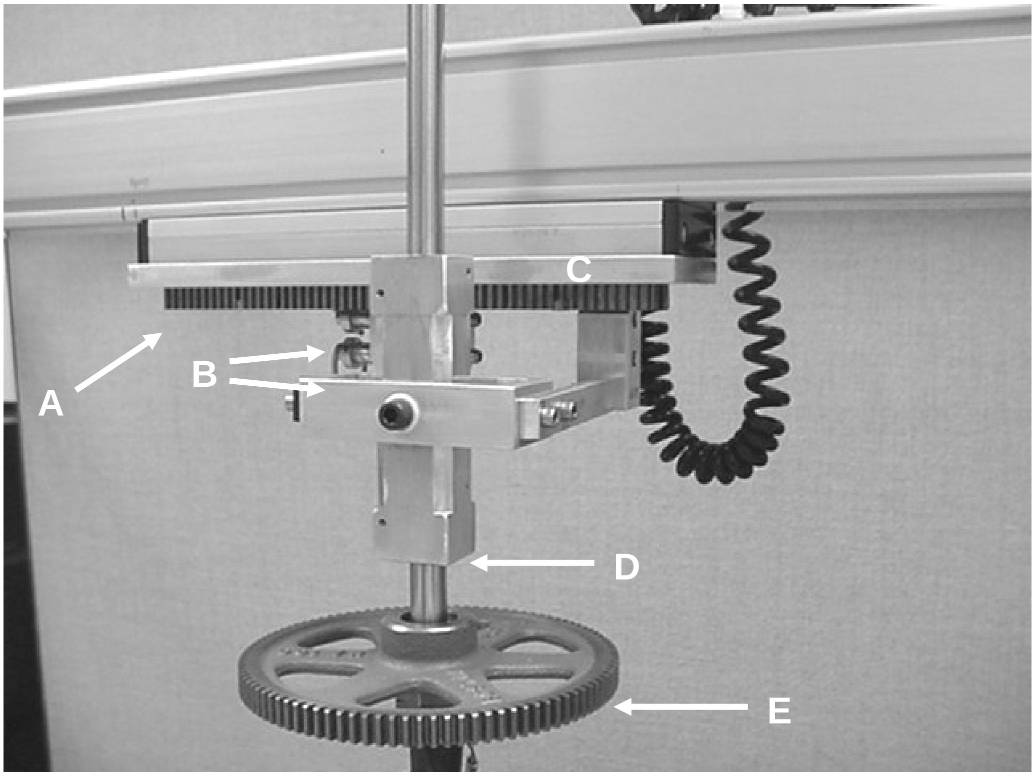


Figure 3. Load Transfer Assembly (LTA) Detail.
This mechanism transfers the desired motion from the linear actuator to the torso.

A. Rack Gear - used during torsional compliance testing
B. Quick release locking pins - allow rapid reposition of the LTA from the position for flexion testing (shown) to the upper position used for torsional compliance testing.
C. Slider - moving platform on the linear actuator.
D. Linear bearing –controls the lateral position of the central rod and slides along the rod permitting flexion of the anatomical trunk.
E. Spur Gear –during torsional compliance testing this gear is driven by the rack gear on the slider.

2.4 Magnetic Limit Switches

Figure 4. Magnetic Limit Switch

The magnetic limit switches are used by the operator to define an appropriate displacement range for the slider. When a known point on the slider passes these switches, their signal state inverts. This information is used by the motion control software to locate an initial home position prior to beginning a programmed displacement pattern. There are three switches: a home position, a maximum positive position and a maximum negative position.

When the device is first turned on, the position of the slider is unknown by the motion control system. A homing routine is executed and the slider is moved to the location defined by the home position switch during the start-up sequence for each test. The sequence of motions begins with an extension until either the home position switch or the maximum positive position switch is encountered. If the maximum or minimum limit is detected, the slider will reverse its direction and begin a return sweep for the home position.

2.5 Safety Components

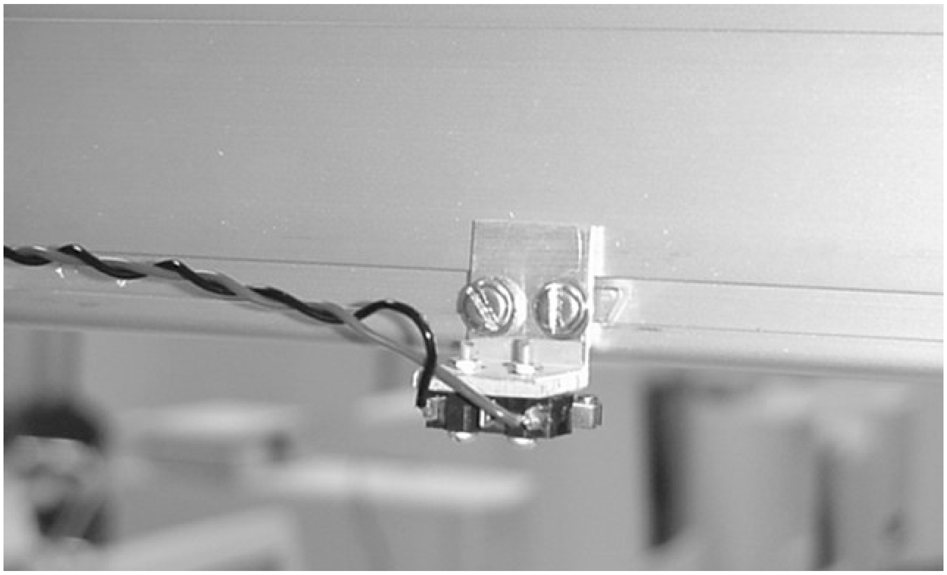


Figure 5. Mechanical Limit Switch

These devices are part of the fail-safe safety system and prevent the test mechanism from being damaged during an unexpected or uncontrolled motion. There are two of these switches located at the extreme limits of the slider travel. When activated, power to the drive motor is cut off, halting all movement.

Figure 6. Run/Kill Switch

This switch is an emergency STOP switch to run. All power is disabled to the motion control system when in the “KILL” position.

NOTE: the system must be set to the “RUN” position prior to power up to enable the device.

2.6 Signal Amplifier

Figure 7. RDP Group Modular 600 Amplifier

The model shown has 8 channels, allowing the integration of 6 strap force transducers. Only two channels are required to provide signal conditioning for the torsion and bending beam load cells.

3.0 Running a Test

3.1 Test Preparation

Each LCS is tested empty. For all compliance testing, fit the LCS onto the compliance tester's 50 percentile male mannequin, using all available adjustments to achieve the best fit as described by the manufacturer. The manufacturer's recommendations should take precedence over the standard strap tension settings listed below, where a conflict occurs. Strap tensions are set using the Chatillon force gauge. When setting tensions, ensure that the strap being tightened is aligned with the buckle to minimize friction through the buckle.

Table 1. Strap Tension Settings

Strap Location	**Biomechanical Model Designation**	**Standard Tension (N)**	**Actual Test Value (N)**
Above the shoulder pad	T1	90 N	
Below the shoulder pad	T2	80 N	
Load lifter	T3	60 N	
Waist belt	T4	90 N	
Upper hip stabilizer	T5	100 N	
Lower hip stabilizer	T6	100 N	
Sternum	T7	60 N	
Other – (describe)	T8		

3.2 Forward Bending Resistance – Set-up

The average range of motion for the unencumbered spine in forward flexion is 80°. Although the torso takes on an initial angle of lean to balance the weight of the load, during level walking, there is little change in this posture. This motion becomes important in dealing with transitory events, such as climbing or ducking down to avoid obstacles.

For the forward bending test, the torso faces the direction of motion. In this test, the axis of rotation (the hinge at the waist) is positioned perpendicular to the horizontal track. The lower section of the torso is locked in position using the two locking bolts on the collar below the hip section. The thrust bearing at the waist must be restrained by tightening the bolt at the front of the flange plate to prevent any rotation of the torso.

Forward bending moment is applied by the programmable linear actuator in the form of a horizontal force acting on a moment arm of 0.93m. Figure 8 shows the details of the Load Transfer Assembly (LTA) configured for the Forward Flexion test. This configuration is also

used for Lateral Flexion tests. The force required to displace the torso is measured with a bending beam load cell located between the actuator slider (C) and the linear bearing (D). The linear bearing supports the vertical rod that is affixed to the upper torso. Maximum excursion of the slider is 1.04 m resulting in a maximum forward bending angle of 48 degrees.

Forward Flexion Assumptions:

Range of normal motion:	0 to 85 degrees forward flexion
Test Range:	0 to 45 degrees

The linear bearing (D) is attached to the slider (C) with two quick release-locking pins (B). Bearing (D) slides along the vertical rod allowing the upper torso to lean forward as the actuator moves the slider horizontally.

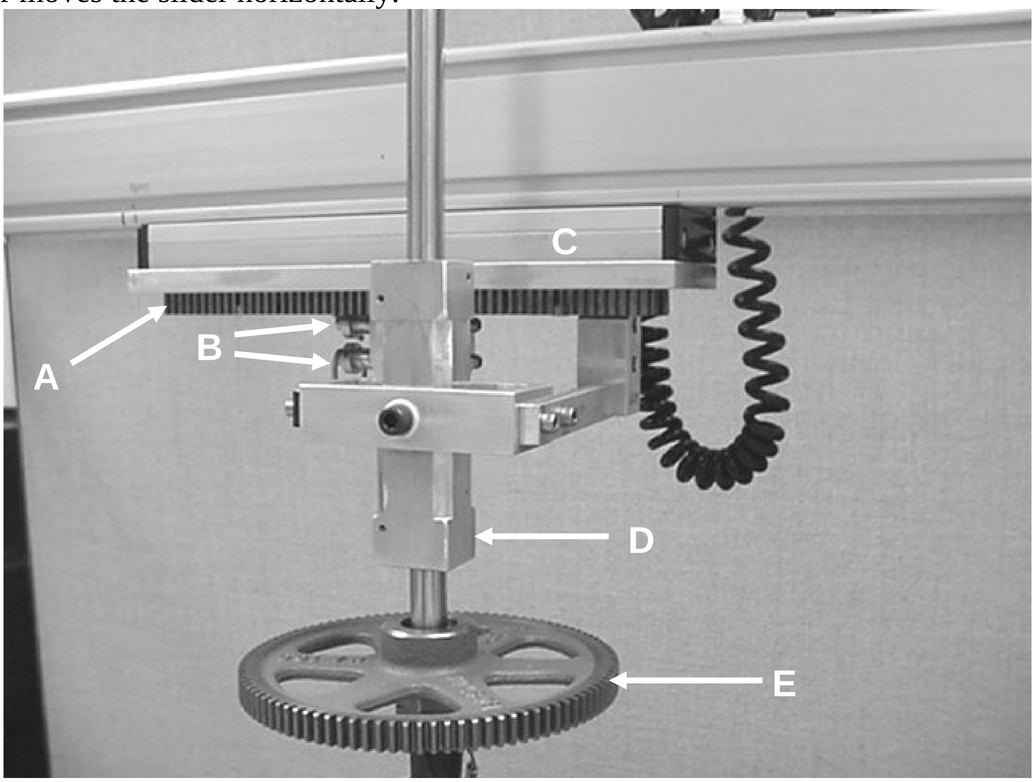


Figure 8. Load Transfer Assembly Detail – Position for Forward and Lateral Bending Tests

A. **Rack Gear, (used for Torsion testing)**
B. **Quick release locking pins**
C. **Slider**
D. **Linear bearing**
E. **Spur Gear, (used for Torsion testing)**

The bending beam load cell located between the slider (C) and the bearing (D) measures the force applied to the vertical rod at every lean angle. This is converted to a moment by multiplying by the moment arm 0.93 m, which is the vertical distance from the load cell to the axis of torso rotation.

Figure 9 is a sketch showing the physical set up for the Forward Bending test.

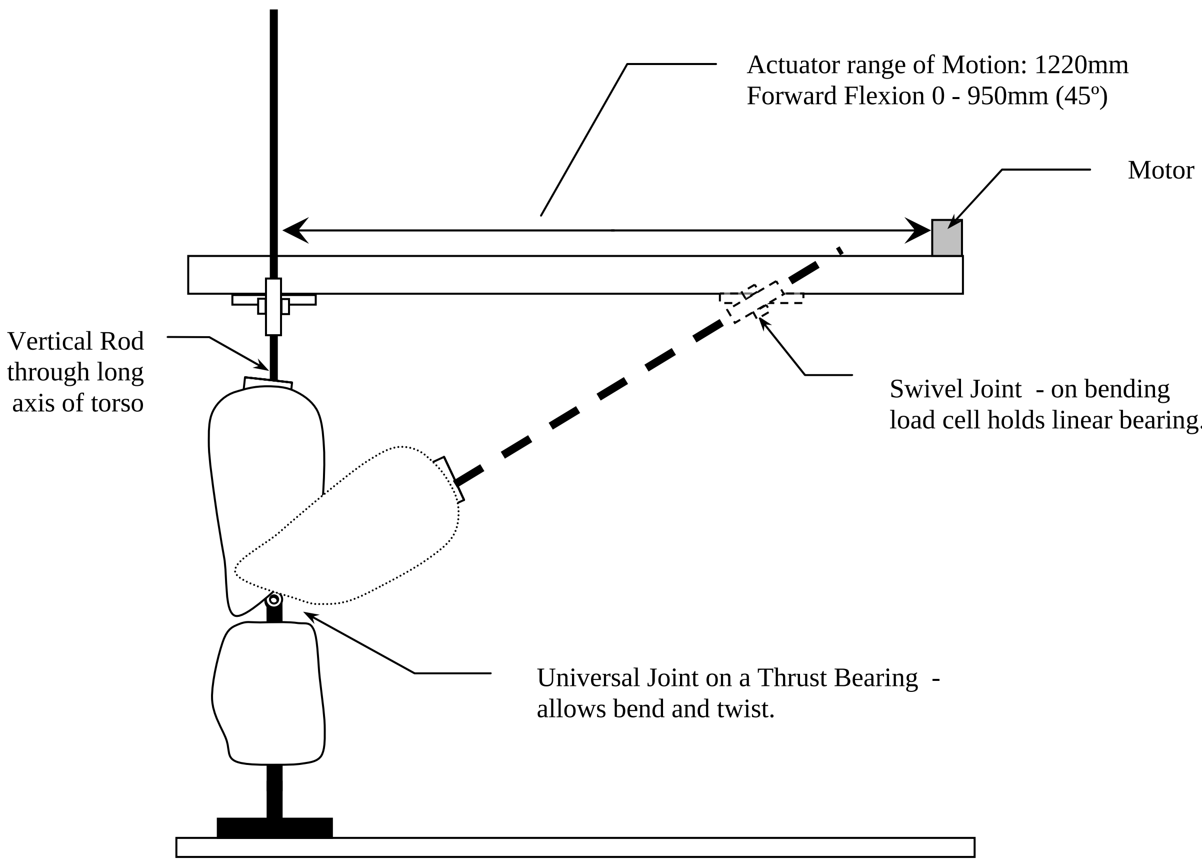


Figure 9. Test Cell Configuration for Forward Bend Testing

The torso must be positioned facing along the actuator travel towards the motor and at the left side of the test cell. The base must be moved along the lower track to the position farthest from the motor. To do this:

1. Ensure that the LTA is configured as shown in Figure 8.
2. If the front of the torso is perpendicular to the actuator, release the two locking screws on the locking collar at the base of the torso, rotate the hip section of the torso to the

orientation shown in Figure 9. Tighten the two lock screws on the lock collar to hold this lower section in position.

3. Gently rotate the upper torso until it is approximately aligned, it should rotate freely on the universal joint and the linear bearing.
4. Retract the stabilizing feet on the movable base and release the lock on the back of the movable base. The torso should be oriented as shown in Figure 9.
5. Unplug the power to the TQ10SD unit. When the controller is off, the slider can be repositioned manually. Note: the universal joint at the waist will allow the torso to buckle, care must be taken to control rotation of the upper body segment to avoid binding of the body segments.
6. Beginning with the lower body segment, move the base towards the left of the test cell, the body will begin to flex at the waist.   At approximately halfway, stop and push the upper slider to the left to realign the body.
7. Repeat until the base is in the marked position for the forward flexion test. Lower and tighten the stabilizing legs on the base. Tighten the locking mechanism at the back of the movable base.
8. Position the overhead slider at the forward flexion zero reference mark.
9. Confirm that the selector switch on the test configuration box is set to Forward Flexion**.** **Note: The setting on the test configuration box is used by the control system to set the zero reference position.   An incorrect setting will result in invalid data.**
10. With the slider in the correct position, plug in the TQ10SD unit.

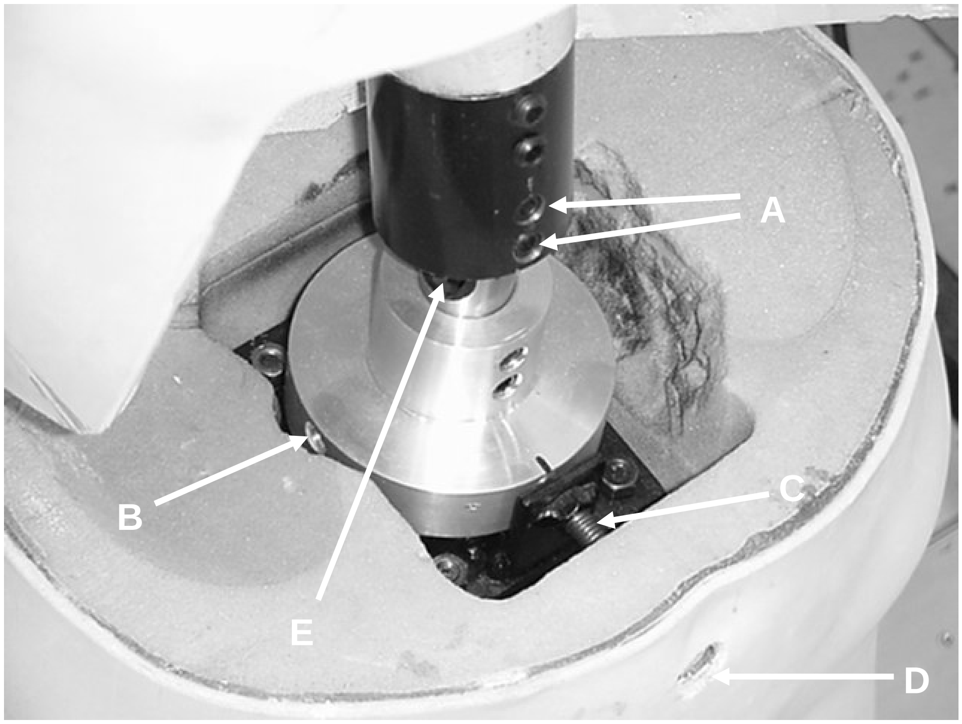


Figure 10. Universal Joint and Thrust Bearing Details

A) Locking collar that permits rotation of the articulation mechanism within the mannequin body.
B) Alternate position for the thrust bearing locking bolt. Used when the lower torso has been rotated 90° counter clockwise for forward flexion testing.
C) Thrust bearing locking bolt; used to lock the thrust bearing flange plate and stop rotation of the torso during flexion testing.
D) Access hole for item (C) thrust bearing locking bolt.
E) Universal joint; used during forward and lateral flexion of the torso.

The axis of the universal joint at the waist must be aligned with the overhead track to avoid binding during the motion. Correct alignment of the torso and universal joint can be confirmed by manually initiating the required bend and checking for free motion.

3.3 Lateral Resistance to Motion - Set-up

The torso is placed in the centre of the test frame facing outwards, (see Figure 1) for the lateral flexion as well as the torsion twist tests. For a sideways lean, excursion of the slider is reduced to 0.31 m, which results in a maximum sideways bending angle of 18°. The average range of motion for the spine in lateral flexion is approximately 50°. The normal range expected during walking gait is about 2-7 degrees rotation about the neutral axis.[1]

Lateral Flexion Assumptions:

The approximate centre of this rotation is T12.

Range of normal motion:	-25 to+25 degrees (side to side) lateral flexion
Test Range:	-18 to +18 degrees

Since the slider must follow the path prescribed by the horizontal track, the universal joint at the waist must be aligned with the overhead track to avoid binding during sideways motion. Releasing the locking collars above and below the torso allows the entire torso to be rotated 90 degrees, bringing the left side of the body in line with the horizontal track. Once aligned, the locking collars must be locked in position.

Confirm the alignment of the torso by manually initiating a sideways lean. When the alignment is satisfactory, tighten the two locking screws on the locking collar just below the fibreglass tube at the base of the torso.

Both the lateral and forward flexion tests use load data from the bending beam load cell. This load cell must be connected to the 4 pin connector marked 'F' (flexion) located on the back of the slider.

NOTE: During flexion testing, the Torsion load cell must be detached and the cabling stowed safely to prevent damage to this conductor.

Set the strap tensions following the recommended values listed in Table 1. Using the Shimpo pull gauge, grasp the end of each strap in the clamp and apply force in-line with the buckle. The strap should be pulled tangentially to reduce friction effects. Tighten each set of straps as a set (i.e. left side then right side) and check each strap a minimum of two times. Record strap tensions in the test record. Before data acquisition, ensure that the torso is at the 0 position by checking the alignment lines on the upper and lower torso on the left side of the body.

3.4 Torsional Resistance to Motion - Set-up

Although the shoulder girdle is capable of considerable independent movement, during walking it moves in unison with the thorax. The transverse rotation of the thorax tends to decrease as walking speed increases. Total relative rotation values range from 2º to 16º over walking speeds of 50 to 93 m/min.

During walking, the shoulders rotate about the vertical axis and the pelvis counter-rotates. Unlike the shoulders, the pelvis increases its rotation as forward velocity increases. This allows the walker to increase their stride length as well as increase their step cadence. Total transverse pelvic rotation ranges from 1 to 25° as walking speed increases from 50 to 105 m/min. The average is about 15°, (+7.5° /-7.5°) at 105 m/min. Adding the shoulder rotation to the pelvis

counter-rotation creates a relative angle of twist that ranges from 2 to 20° in different individuals, depending on their personal gait pattern.

Rotation about Vertical Axis Assumptions:

Range of normal rotation:	2 - 20 degrees (total) for gait 50 - 105 m/min (3 to 6.3 kph)
Average normal range:	10 degrees total relative rotation
Test Range:	12 degrees total relative rotation

As in the lateral flexion tests, the torsional test requires the torso to be positioned in the centre of the test frame, facing outwards (see Figure 1). Lock the torso in the upright position by moving the bending beam load cell up onto the upper frame rail. Fix this assembly in position by restraining the 'dummy' beam (non instrumented side) with two locking pins. Figure 11 shows the correct configuration of the LTA for a Torsional resistance test. Position the slider in the correct central position for the torsional test first then and adjust the alignment of the torso by carefully positioning the torso base. With the TQ10SD unit unplugged, confirm the alignment by manually rotating the upper torso. Check that the rack and spur gears mesh freely with no binding. When this is satisfactory lock the torso in position.

The Torsion test uses load data from the torsion load cell only. This load cell must be connected to the 4 pin connector marked 'T' (Torsion) located on the back of the slider.

NOTE: During Torsion testing, the bending beam load cell must be detached and the cabling stowed safely to prevent damage to this conductor.

Set the strap tensions following the recommended values listed in Table 1. Using the Shimpo pull gauge, grasp the end of each strap in the clamp and apply the force in-line with the buckle. The strap should be pulled tangentially to reduce friction effects. Tighten each set of straps as a set (i.e. left side then right side) and check each strap a minimum of two times. Record the strap tensions in the test record. Before data acquisition, ensure that the torso is at the 0 position by checking the alignment lines on the upper and lower torso on the left side of the body.

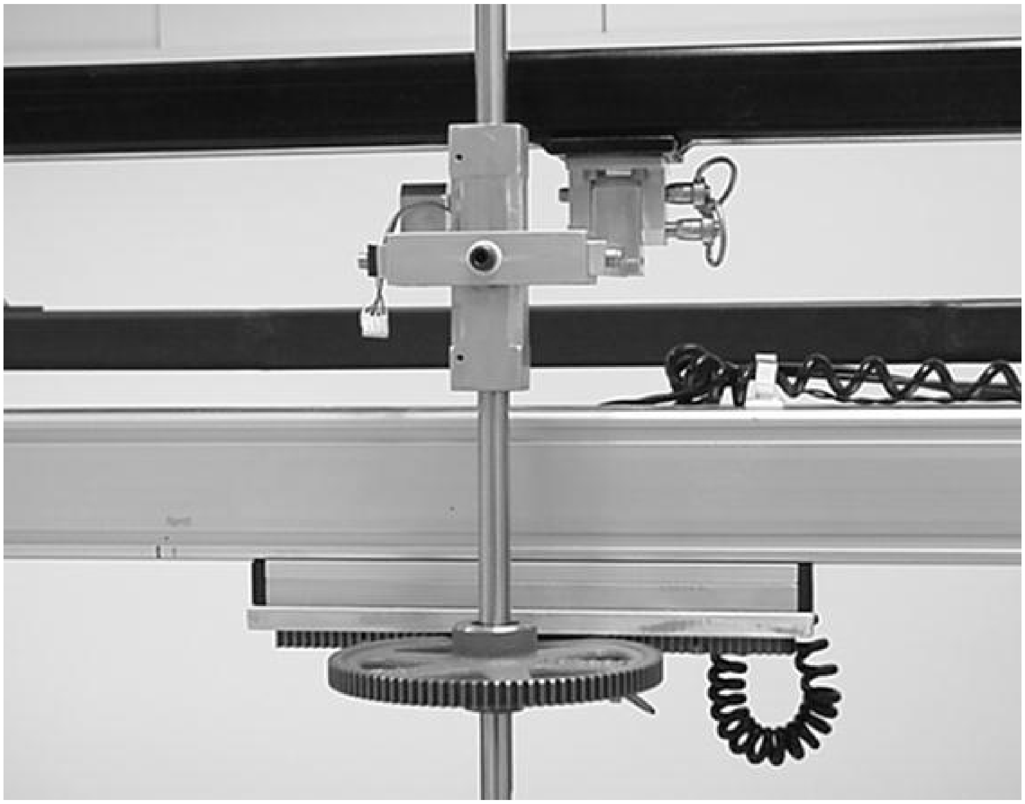


Figure 11. Load Transfer Assembly Configuration for a Torsional Resistance Test.

4.0 Description of Data Acquisition

During each test run, analog signals from the load cells and the position of the slider are captured with a data acquisition system consisting of an A to D board, (National Instruments PCI6023E) and the data acquisition software LabVIEW™ v6.0 (National Instruments Inc.) Each data set is saved on the hard drive, under a user defined filename for post-processing using an MS Excel® macro.

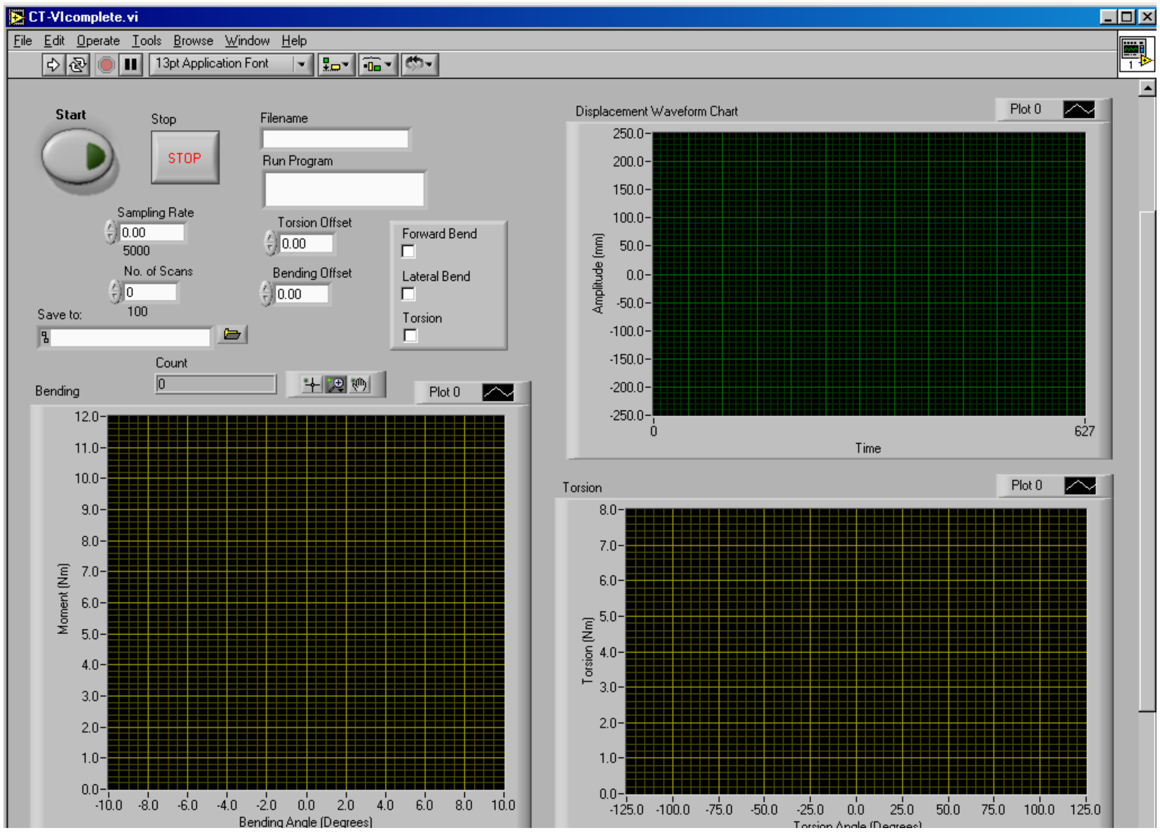


Figure 12. User Interface Screen

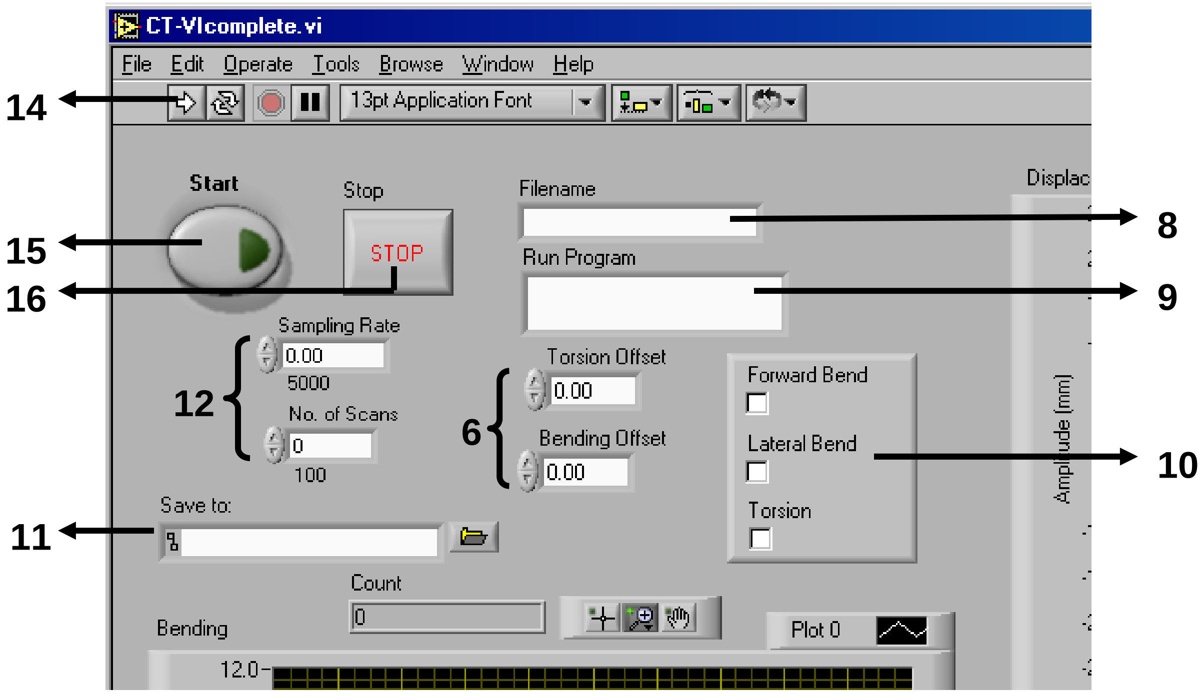


Figure 13. User interface screen illustrating numbers that correspond with the steps listed in 4.1.

4.1 Data Acquisition: Steps To Follow

[**SAFETY NOTICE** Motion may be immediately halted by pressing the **"KILL"** button (Figure 6)]

1. Open LabVIEW™ program
2. Click on **Open VI**.
3. Run the Compliance Tester Virtual Instrument (**CT-VIcomplete.vi**)
4. Select the type of test you wish to perform.
5. Do you have current load cell offset values? (Required for each new test)

   YES: Continue on to the next step

   NO: Perform load cell offset test, (refer to section 4.2)
6. Enter Torsion Load Cell and Bending Load Cell offset values, (these values will be automatically subtracted from the captured signals, in order to zero calibrate the load cells)
7. Do you have a current baseline file? (Required every time the torso is moved to begin a new type of test)

   YES: Continue on to the next step

NO: Perform baseline test, (refer to 4.3)

8. Type in the Filename of the Compumotor program you require, (see below): (eg. **c:\ma6000\'program'.prg**)

    For a Forward Bend test, type: **c:\ma6000\fwdbend.prg**

    For a Lateral Bend test, type: **c:\ma6000\latbend.prg**

    For a Torsion test, type: **c:\ma6000\torsion.prg**

9. Type in the words **run 'program'** followed by a <u>carriage return</u>, (***NOTE* 'program'** = fwdbend, latbend, or torsion).

10. Select one of the following, depending on the required test:

    Forward Bend

    Lateral Bend

    Torsion

11. Type in an output filename for Save to File.

    Data will be saved in ascii format, (eg. **c:\temp\temp1.txt**)

12. * Set the sampling rate (eg. 5000) – (This determines how often an analog-to-digital conversion takes place).

    * Set the number of scans (eg. 100) – (A scan is one acquisition or reading from each channel in the channel string).

    Completion of steps 1 through 12 will:

    Initialize motion control program

    Load operating system

    Load motion program defined by **'program'.prg**

    (A Start button appears when the above tasks are complete)

13. Confirm that the physical set-up of the compliance tester matches the type of test you have selected.

    [****WARNING**** Mismatching the test type and the physical set up of the equipment will result in damage to the equipment.]

14. Push the **RUN** button.

    (The RUN button disappears)

15. Push the **Start** button.

    This will: Begin motion

Begin Data Acquisition

16. Push the **STOP** button to stop data acquisition.

***** If you wish to perform another test, return to step four above, (change the filename when saving, in order to retain the new data in a separate file).

***** If you do not wish to run another test, push the **Stop** button.

After stopping, the Forward or Lateral or Torsion graph will display and data will be saved to file.

4.2 Calculating Load Cell Offset Values

Once the Compliance Tester Virtual Instrument (CT-VIcomplete.vi) program is open in LabVIEW™, perform the following steps:

1. Ensure the load cells offsets are set to zero, (in LabVIEW™).
2. Type in the Filename of the Compumotor program required to calculate Torsion Load Cell and Bending Load Cell offset values:

   c:\ma6000\offset.prg
3. Type in the words **run offset**, followed by a carriage return.
4. Select Torsion from your list of three options, (***NOTE*** for this test the torso will remain in the zero reference position during data acquisition).
5. Type in a Filename for Save to File, which includes the current date, (eg. **Offset Values 0624**)

   Data will be saved in a text file format, (eg. **c:\temp\offsetvalues0624.txt**)
6. * Set the sampling rate (eg. 5000) – (This determines how often an analog-to-digital conversion takes place).

   * Set the number of scans (eg. 100) – (A scan is one acquisition or reading from each channel in the channel string).

   Completion of steps 1 through 6 will:

   Initialise motion control program

   Load operating system

   Load program defined by **'program'.prg**

   (A Start button appears when the above tasks are complete)

7. Confirm that the physical set-up of the compliance tester is in the zero reference position.
8. Push the **RUN** button.
   (The RUN button disappears)
9. Push the **Start** button.
   This will: Begin Data Acquisition
10. Gather data for a minimum of 10 seconds, then press the **STOP** button.
11. Open this data file in MS Excel® and calculate the average offset values for both the Torsion and Bending Load Cells.
12. Return to section 4.1, step #6.

4.3 Performing a Baseline Test

Once you have entered current load cell offset values, perform the following steps:

1. Type in the Filename of the Compumotor motion program you require a baseline data set for, (see below):
   (eg. **c:\ma6000\'program'.prg**)

   For a Forward Bend test, type: **c:\ma6000\fwdbend.prg**
   For a Lateral Bend test, type: **c:\ma6000\latbend.prg**
   For a Torsion test, type: **c:\ma6000\torsion.prg**
2. Type in the words **run 'program'** followed by a carriage return, **(*NOTE* 'program'** = fwdbend, latbend, or torsion).
3. Select the required test:
   Forward Bend
   Lateral Bend
   Torsion
4. Type in an output filename for Save to File, which includes the current date, (eg. **Fwd baseline 0624**, **Lat baseline 0624**, or **Torsion baseline 0624**, depending on selected test).
   Data will be saved in a text file format, (eg. **c:\temp\fwdbaseline0624.txt**)
5. * Set the sampling rate (eg. 5000) – (This determines how often an analog-to-digital conversion takes place).

* Set the number of scans (eg. 100) – (A scan is one acquisition or reading from each channel in the channel string).

Completion of steps 1 through 5 will:

Initialize motion control program

Load operating system

Load motion program defined by **‘program’.prg**

(A Start button appears when the above tasks are complete)

6. Confirm that the physical set-up of the compliance tester matches the type of test you have selected.

   [****WARNING**** Mismatching the test type and the physical set-up of the equipment will result in damage to the equipment.]

7. Push the **RUN** button.

   (The RUN button disappears)

8. Push the **Start** button.

   This will: Begin motion

   Begin Data Acquisition

9. Run for a min of 30 cycles (approx. 20 sec.), and then push the **STOP** button.
10. Return to section 4.1, step #8, in order to continue the main test.

5.0 Data Reduction

Once you have recorded your baseline and main tests, the next step is to analyse the raw data and correct for the baseline values in order to calculate the dynamic stiffness of the equipment being tested. Load cell and position data is converted into moment versus angular rotation data and the average of the multiple test cycles calculated. The average of the unloaded (baseline) moment versus angular rotation is then subtracted from the test data leaving only the bending moment induced by the tested load carriage equipment. Two parameters are then calculated from this:

1. Linear slope of the moment during flexion and extension, (Compliance coefficient K.)
2. Hysteresis of the flexion/extension cycle. (Estimated energy cost = E)

The following keystrokes begin data analysis:

1. In MS Excel®, open the text format data file containing the values for your regular test.

   To do this:

   a) Open an existing document.
   b) Change the type of files to '**All Files**' and select your data file.
   c) Click on the **OPEN** button, (the Text Import Wizard will appear).
   d) Ensure that the selected file type in step 1 is **'Delimited'**, and then click the **NEXT** button.
   e) Ensure that the selected delimiter in step 2 is **'Tab'**, and then click the **NEXT** button.
   f) Ensure that the selected column data format in step 3 is **'General'**, and then click the **FINISH** button.
2. You should now see four columns of data, including Flexion Angle, Flexion Moment, Torque Angle, and Torque Moment.
3. In order to correct for your baseline values, you must run the **Dynamic Stiffness** macro.

   To do this:

   a) Press the keys Alt + F8, (the Macro Dialog Box will appear).
   b) Select the **Dynamic Stiffness** macro and click on the **RUN** button.

4. When prompted, enter the current baseline filename that corresponds with your data set.
5. The **Dynamic Stiffness** macro automatically performs the following:
    a) Subtracts the forces due to inertia and friction in the test apparatus from the total force recorded during the compliance test,
    b) Plots resultant force versus displacement angle,
    c) Calculates the compliance coefficient for the equipment being evaluated,
    d) Summarizes the test results in a table.

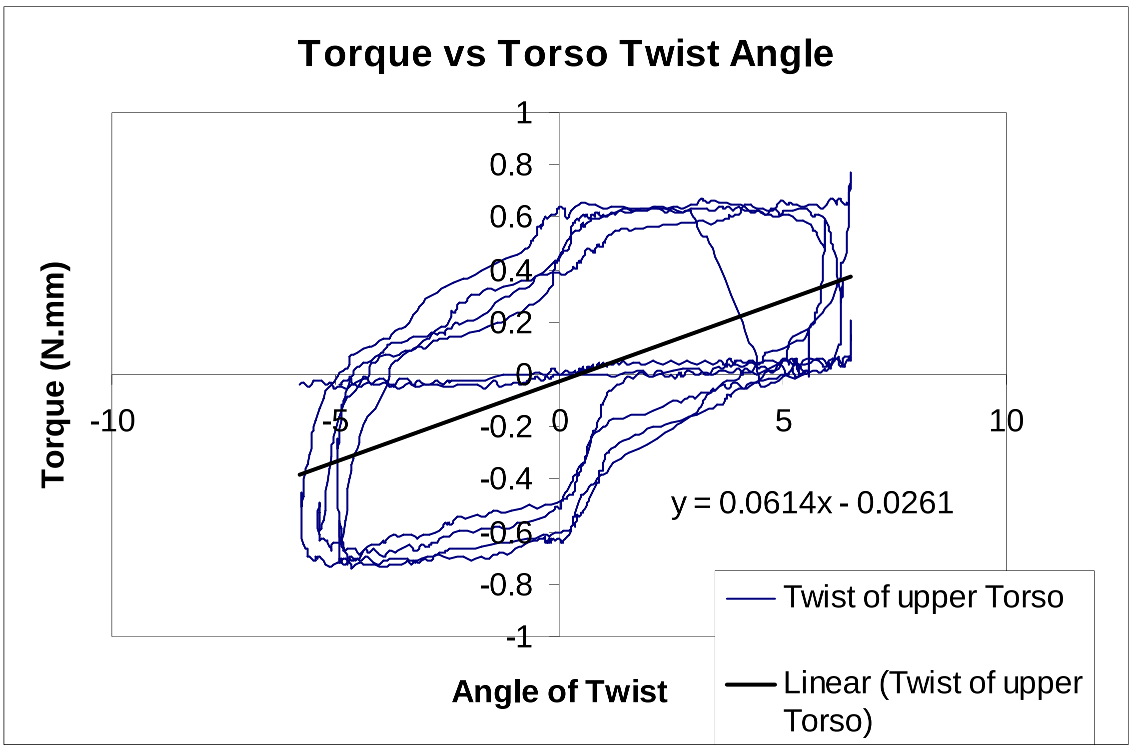


Figure 14. Graph showing the typical baseline 'torque versus torso twist angle' values.

6.0 Conclusion – Future Work

Previously, slow flexion was used to determine a flexion stiffness value approximately analogous to K_F. Future work is planned in order to link this new device with previously validated stiffness testing.[3]

7.0 References

1. Inman, V., Ralston, H., Todd, T. *Human Walking*, 1981.

2. DCIEM Contract # W7711-S-7356, Section D – *Development of Acceptance Criteria for Physical Tests of Load Carriage Systems*, 1996.

3. Stevenson, J.M. *et al*. 1995. Background document for advanced personal load carriage system for the Canadian Armed Forces. DCIEM Contract #W7711-5-7273/001/TOS.

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(U) This report represents the User's Manual for the 3D dynamic load carriage simulator and automated test cell. Contained within this report are the hardware and software components in addition to instructions for users to run the system. If the system is ever moved to a new location, this manual must be taken with it for set−up and data acquisition. The changes to the automated programmable motion control system have created a number of functions not possible with the previous system. These functions include: 1) highly repeatable motion profiles independent of the operator; 2) determination of the system stiffness under dynamic conditions; 3) provision for quantitative validation of models of load carriage devices; 4) determination of the frequency response of LC suspension systems; and 5) creation of an automated test cell requiring minimal operator expertise and low cost for possible sale to support other countries modelling efforts.

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(U) Load carriage; Dynamic Biomechanical Model; Dynamic Load Carriage Compliance Tester Automated Test Cell; data acquistion; compliance tester; forward flexion; LabVIEW